# Hazard mapping over wastewater treatment plant as point critical infrastructures using a multi-hazard, multi-scale approach

*Original*
Hazard mapping over wastewater treatment plant as point critical infrastructures using a multi-hazard, multi-scale approach / Castiglione, M.; Beringheli, G.; Fabio Corsino, S.; Torregrossa, M.; Castro Rodriguez, D. J.; Demichela, M.; Barresi, A.. - ELETTRONICO. - 4:(2025), pp. 72-80. (Intervento presentato al convegno 14th IWA Specialized Conference on the Design, Operation and Economics of Large Wastewater Treatment Plants (LWWTP2024) tenutosi a Budapest nel 8-12 September 2024) [10.22618/TP.EI.20254.116009].

*Publisher:*
Trivent Publishing

*Published*
DOI:10.22618/TP.EI.20254.116009

# 14TH IWA SPECIALIZED CONFERENCE on the Design, Operation and Economics of Large Wastewater Treatment Plants (LWWTP2024)

## - SELECTED PAPERS -

EDITED BY

**MIKLÓS PATZIGER**

TRIVENT

TRIVENT
PUBLISHING

# *14th IWA Specialized Conference on the Design, Operation and Economics of Large Wastewater Treatment Plants (LWWTP2024)*

*- selected papers -*

Edited by

Miklós Patziger

*Engineering and Industry, vol. 4*

14th IWA Specialized Conference on the Design, Operation and Economics of Large Wastewater Treatment Plants (LWWTP2024) - selected papers -
Ed. Miklós Patziger

eISBN 978-615-6696-67-0
Engineering and Industry, vol. 4
ISSN 2939-5615
Responsible publisher: Teodora C. Artimon
https://trivent-publishing.eu/47-engineering-and-industry

First published in 2025 by Trivent Publishing

Trivent Publishing
1119 Budapest, Etele ut 59–61, Hungary
For more information, visit our website: http://trivent-publishing.eu

# TABLE OF CONTENTS

*14th IWA Specialized Conference on the Design, Operation
and Economics of Large Wastewater Treatment Plants
(LWWTP2024) – Selected Papers*

# Hazard Mapping Over Wastewater Treatment Plants as Point Critical Infrastructures Using a Multi-Hazard, Multi-Scale Approach

**Maria Castiglione[1*], Giuseppe Beringheli[1], Santo Fabio Corsino[1], Michele Torregrossa[1], David Javier Castro Rodriguez[2], Micaela Demichela[2], Antonello Barresi[2]**
[1] University of Palermo, Palermo (Italy), Viale delle Scienze Ed.8, 90128
[2] Politecnico di Torino, (Italy), C.so Duca degli Abruzzi 24, 10129
[*]Maria Castiglione, maria.castiglione01@unipa.it

***Keywords:*** *Climate change, wastewater treatment plants, NaTech, GIS, multi-hazard, critical infrastructures.*

## *ABSTRACT*

*Nowadays, natural extreme events are increasing in frequency and intensity due to climate change. These phenomena negatively impact critical infrastructures, such as wastewater treatment plants (WWTPs), resulting in a loss of their functionality and the generation of hazards to the environment and the population. It is important to identify and assess the hazards to which critical infrastructure is subject due to natural extreme events. Based on these considerations, through this work, the vulnerability of the territory and WWTPs of Sicily (south of Italy) was evaluated by using Geographic Information Systems (GIS) tools and a multi-hazards approach. The multi-hazard approach allowed determining the combined effect on the territory of different hazards (seismic, hydraulic, geomorphological and coastal), starting from the assessment of individual hazards and considering their possible simultaneous action. To this end, a multi-hazard spatial index was defined and subsequently mapped. This index represents an essential starting point for later defining a regional multi-hazard index map. Additionally, potential environmental and health consequences related to the occurrence of extreme events near wastewater treatment plants were assessed. This approach provides valuable guidance to local and regional authorities, aiding in the prevention, management, and mitigation of multi-hazard natural disasters.*

**DOI: 10.22618/TP.EI.20254.116009**

# Hazard Mapping Over Wastewater Treatment Plants as Point Critical Infrastructures Using a Multi-Hazard, Multi-Scale Approach

**Maria Castiglione[1*], Giuseppe Beringheli[1], Santo Fabio Corsino[1], Michele Torregrossa[1], David Javier Castro Rodriguez[2], Micaela Demichela[2], Antonello Barresi[2]**
[1] University of Palermo, Palermo (Italy), Viale delle Scienze Ed.8, 90128
[2] Politecnico di Torino, (Italy), C.so Duca degli Abruzzi 24, 10129
[*]Maria Castiglione, maria.castiglione01@unipa.it

***Keywords:*** *Climate change, wastewater treatment plants, NaTech, GIS, multi-hazard, critical infrastructures.*

## *ABSTRACT*

*Nowadays, natural extreme events are increasing in frequency and intensity due to climate change. These phenomena negatively impact critical infrastructures, such as wastewater treatment plants (WWTPs), resulting in a loss of their functionality and the generation of hazards to the environment and the population. It is important to identify and assess the hazards to which critical infrastructure is subject due to natural extreme events. Based on these considerations, through this work, the vulnerability of the territory and WWTPs of Sicily (south of Italy) was evaluated by using Geographic Information Systems (GIS) tools and a multi-hazards approach. The multi-hazard approach allowed determining the combined effect on the territory of different hazards (seismic, hydraulic, geomorphological and coastal), starting from the assessment of individual hazards and considering their possible simultaneous action. To this end, a multi-hazard spatial index was defined and subsequently mapped. This index represents an essential starting point for later defining a regional multi-hazard index map. Additionally, potential environmental and health consequences related to the occurrence of extreme events near wastewater treatment plants were assessed. This approach provides valuable guidance to local and regional authorities, aiding in the prevention, management, and mitigation of multi-hazard natural disasters.*

## INTRODUCTION

Climate change is progressively modifying the magnitude and recurrence of natural events such as floods, storms, and heat waves (Pilone et al., 2021). Higher temperatures contribute to increasing the amount of atmospheric moisture available during storms. Consequently, the water cycle is accelerated and intensified, influencing the spatial and temporal distribution of precipitations. In addition, climate change has also been considered an accelerator worsening coastal erosion process by raising mean sea level (Pang et al., 2023).

Therefore, to address the impacts of climate change, it is important to identify areas and objects that may be affected by these events (Masud & Khan, 2024). Critical infrastructures constitute a central element of the analysis. These are large-scale, man-made systems that function interdependently to produce and distribute essential goods. In particular, an infrastructure is defined as critical if its failure or destruction has a significant impact on health, environmental, safety, economic, and social well-being. They are generally built to exist over long periods, which means elements will be exposed to both rapid-onset (e.g., storm surge) and slow-onset (e.g., sea level rise) events. For this reason, their response to climate change is of utmost importance (Shakou et al., 2019).

The European Commission has issued Directive 2022/2557 on the resilience of critical entities, by requiring Member States to identify and assess their risks, emphasizing the influence of all relevant natural and man-made hazards that might result in incidents.

Natural hazards, such as earthquakes, floods, or storms, can trigger the release of toxic substances, fires, and explosions when impacting industrial installations. These types of events are called Natech (natural hazard triggered technological) accidents. Impacts on industrial operations and hazardous infrastructure are a recurring but often overlooked feature in many natural disaster situations. With climate change affecting the intensity and frequency of some natural events, Natech risk has become a topic of concern for disaster risk management at local, national, and international levels. (Krausmann et al., 2017).

The Intergovernmental Panel on Climate Change (IPCC) developed a definition for the concept of vulnerability as the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes (Langsdorf et al., 2022).

In this scenario, wastewater treatment plants are a recognised critical section within industrial plants, particularly the Major Hazards Industries (MHIs) (Casson Moreno et al., 2018). They are fundamental for modern societies and sanitation protection, in particular in densely populated regions where large volumes of wastewater are generated (Li et al., 2023).

The records in industrial databases often report instantaneous consequences such as accidents, releases, explosions, which harm people and the environment. In water treatment plants, the effects are often related to the loss of functionality (Casson Moreno et al., 2018). Extreme weather can interrupt the services and treatment efficacy of wastewater infrastructures, leading to the discharge of untreated or insufficiently treated wastewater into the natural environment (Labonté-Raymond et al., 2020). In this work, vulnerability assessment and detection of signals within multi-hazard contexts where wastewater treatment plants are located is the first part of operationalizing resilience, considering the theoretical concepts defined by Beltramino et al. (2022) and developed for industrial infrastructure by Castro Rodriguez et al. (2023).

Considering all the above, the goal of this study was to represent the territorial vulnerability associated with wastewater treatment plants (WWTPs) in the southern Italian region of Sicily.

Most of the scientific knowledge about hazard assessment protocols focused on individual hazards. Although useful for dealing with specific hazards, the single-hazard approach has significant limitations in overall disaster risk management. One of its main drawbacks is its limited focus on one type of hazard at a time, which does not consider the complex interaction between different hazards. Natural disasters often occur concurrently, where one event can trigger or exacerbate another. By focusing on a single hazard, this approach neglects these cascading effects, resulting in an incomplete understanding of the overall risk. Furthermore, the single-hazard approach might lead to an inefficient allocation of resources. Resources may be heavily invested in mitigating one type of hazard while neglecting others that may be more likely or severe. This misallocation can leave communities and territory vulnerable to unaddressed risks. In addition, mitigation measures designed for one risk may inadvertently increase vulnerability to another (UNDRR, 2020).

In this scenario, a multi-hazard approach is a new concept that is becoming commonplace in risk reduction plans, in contrast to the classical approach of considering each hazard and its potential impacts separately. Utilizing a suitable multi-hazard approach grounded in existing data and knowledge can result in the creation of an interactive and comprehensible map. This map facilitates the visualization of both individual and combined hazards. The incorporation of this approach into Geographic Information Systems provides valuable insights to local and regional authorities, aiding in the prevention, management, and mitigation of multi-hazard natural disasters (Mladineo et al., 2022).

The novelty of the study is related to the application of the multi-hazard approach in the context of wastewater treatment plants in order to assess the hazards to which they are subjected due to the occurrence of extreme natural events with a view to implementing structural and non-structural risk mitigation measures in the future. The definition of a territorial multi-hazard index with a special focus on individual facilities is an essential starting point for the upgrading and improvement of the facility itself. This index allows an integrated assessment and management of the various hazards to which the structure may be exposed, such as seismic, hydrological, industrial, and environmental. In other words, this study pursues two main objectives: assessing the extent to which the territory is exposed to hazards (floods, earthquakes, and landslides) and evaluating the resilience of WWTPs. The results of the study could contribute to a better understanding of the strategies needed to improve resilience to multiple hazards.

## METHODS

The methodology framework to assess territorial vulnerability considered four types of natural hazards: earthquake, hydraulic, geomorphological, and coastal. The study was carried out on a regional scale, considering the Sicilian territory a significant case study given the coexistence of several hazards. Spatial analyses were developed using data on wastewater treatment plants provided by the Sicilian Region and integrated water service bodies. Space-dependent analysis was developed using geographical information systems (GIS). From the provided information, firstly, the WWTPs were represented as point infrastructures, distinguishing between existing, abandoned, and expected. A detailed analysis was conducted at a municipal level. The municipality of Palermo was considered as a case study. Palermo is the biggest city in Sicily and the fifth-largest city in Italy. It covers an area of 158 $km^2$ and has a population of about 700,000 inhabitants.

The municipality of Palermo is served by two WWTPs: “Acqua dei Corsari” and “Fondo Verde” (Figura 1). The former was completed in its first phase with a capacity of 440,000 population equivalent (PE) and is currently operating at around 375,000 PE, treating the wastewater from south part of the city. Located at an altitude of approximately 7-10 meters above sea level, Acqua dei Corsari WWTP faces challenges primarily due to the fragmentation of the landscape caused by linear infrastructures. Notable among these are a coastal road connecting Palermo to Messina, a railway system running along the inland part of the plain, and the internal network of provincial and municipal roads connecting coastal settlements with those in the hinterland of Palermo. The coastal stretch closing the plain is mainly characterized by sandy beaches with a continuous, naturally shaped profile of significant interest. However, these beaches have not been designated for swimming for a long time. The treated effluent is discharged into the sea through an underwater pipeline located about 1600 meters from the coast. Considering that Acqua dei Corsari WWTP borders the territory of a small town (Villabate), the latter has also been included in the analysis. Fondo Verde treatment plant, on the other hand, was designed to serve 105,000 PE and is currently serving about 65,000 PE. Located at an altitude of 20-25 meters above sea level, the surrounding area of the Fondo Verde plant includes several key infrastructures, such as roads and railway lines connecting various parts of the city and the surrounding areas. In this case, the treated effluent currently discharges into the sewage system. The plant is being converted into a pre-treatment facility for incoming effluents and a relay station to the Acqua dei Corsari wastewater treatment plant, including the construction of an emergency discharge pipe.

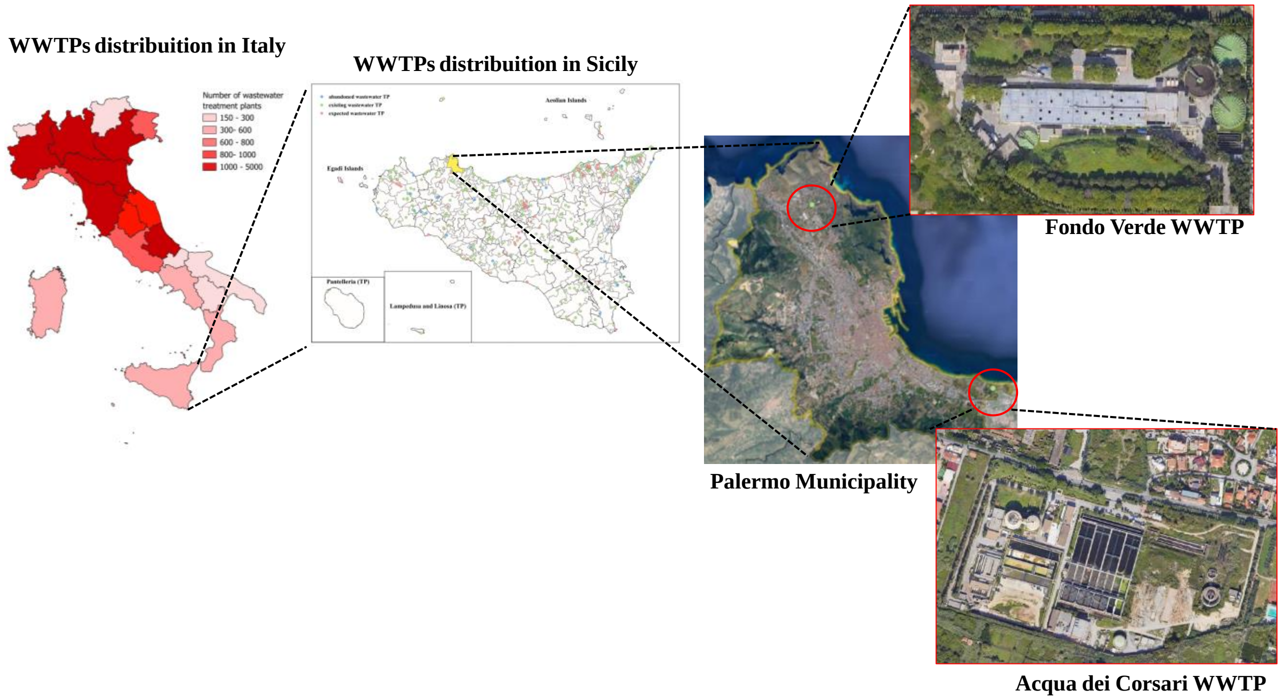


Figure 1. Multi-scale analysis of wastewater treatment plants.

After having identified the WWTPs, the natural hazards (hydraulic, geomorphological, seismic, and coastal) were assessed. In particular, the landslide and hydraulic hazard maps (PAI) provided by the Italian Superior Institute for Environmental Protection and Research (ISPRA) and the Basin Authority of the Region of Sicily were used. The seismic hazard maps were provided by the National Institute of Geophysics and Volcanology (INGV) and the Civil Protection of the Region of Sicily. Focusing on the Sicilian region, each hazard map was harmonized so that H1 corresponded to the lowest hazard and 4 corresponded to the highest. Then, a score was assigned to each hazard class: 0.25 for H1; 0.50 for H2; 0.75 for H3; 1.00 for H4 (Figure 2). The harmonization of maps allows all hazard zones to be converted into a common format to facilitate comparison, as their definitions generally vary between different maps. Harmonization ensures that hazards are uniformly defined and classified so they can be overlaid, enabling the identification of areas with cumulative hazards.

Hereafter, a multi-hazard GIS-analysis was applied at the municipal scale. The aim was to characterize vulnerability scenarios considering the bidirectional interaction between industry (WWTPs) and territory (Castro Rodriguez et al., 2023).

The territory was divided into a grid with 200 m x 200 m cells.

Individual hazard indicators $\boldsymbol{HI_j}$ (0-1) were calculated for each cell. Specifically:

$\boldsymbol{HI_s}$: seismic hazard indicator
$\boldsymbol{HI_g}$: geological hazard indicator
$\boldsymbol{HI_h}$: hydraulic hazard indicator
$\boldsymbol{HI_c}$: coastal hazard indicator.

The value of the individual hazard indicator $HI_j$ was calculated as the sum of the products of each specific hazard class in the cell, multiplied by the corresponding weight. This weight was obtained by dividing the area of each hazard portion by the total area of the cell, according to its hazard class.

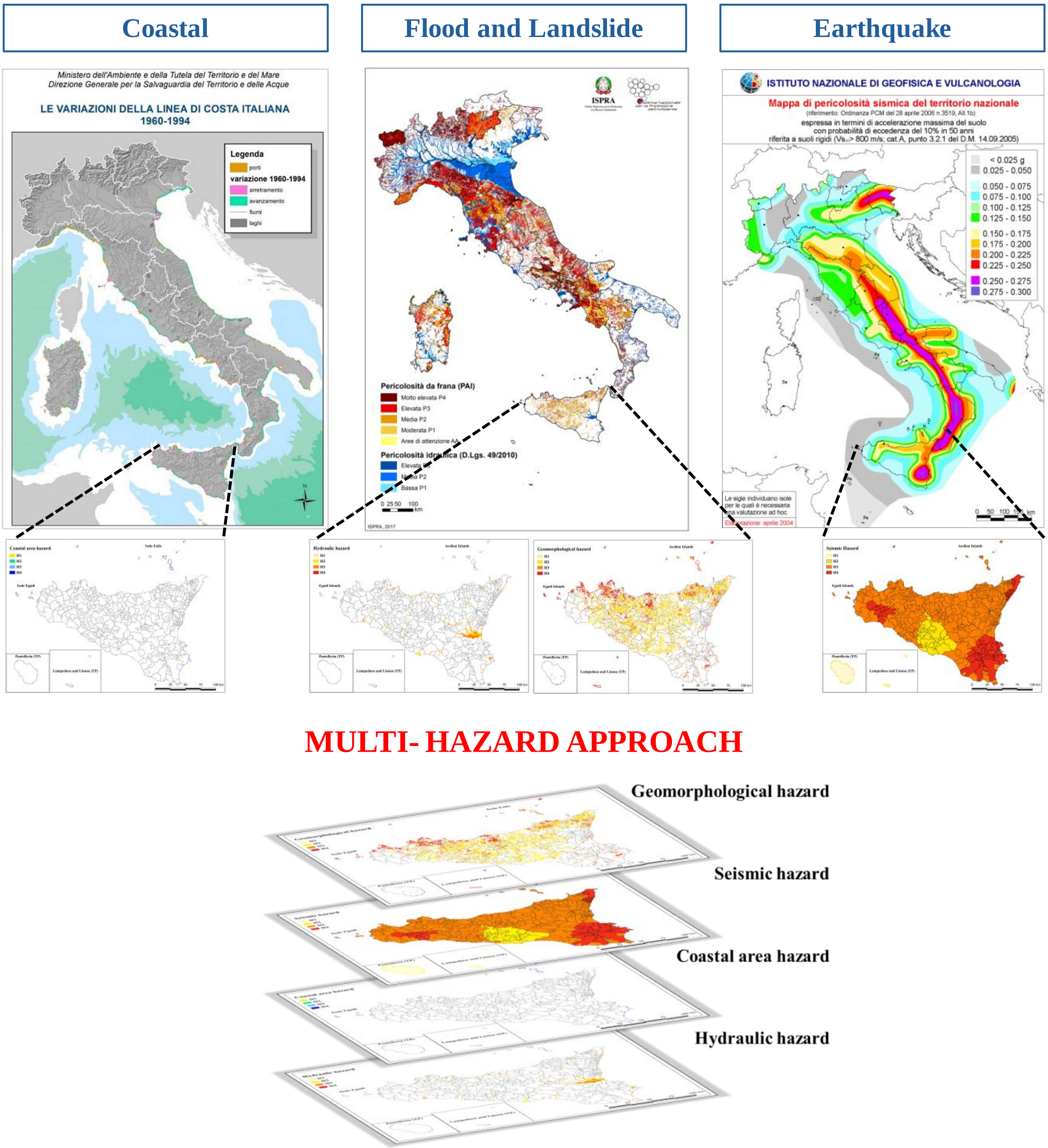


Figure 2. Multi scale analysis of natural hazards.

$$HI_j = \sum_{i=1}^{n} H_i y_i \tag{1}$$

$$y_i = \frac{\sum A_i}{A_{tot}} \tag{2}$$

where

$H_i$ is the value of the score that was assigned to each element belonging to the $i$-th hazard class 0.25 for H1; 0.50 for H2; 0.75 for H3; 1.00 for H4.

$y_i$ is the weight of each element belonging to the i-th hazard class.

$n$ is the number of hazard class (1 ÷ 4)

$A_i$ represents the area of the portion of the $i$-th Hazard (respectively H1, H2, H3, H4) falling within the cell.

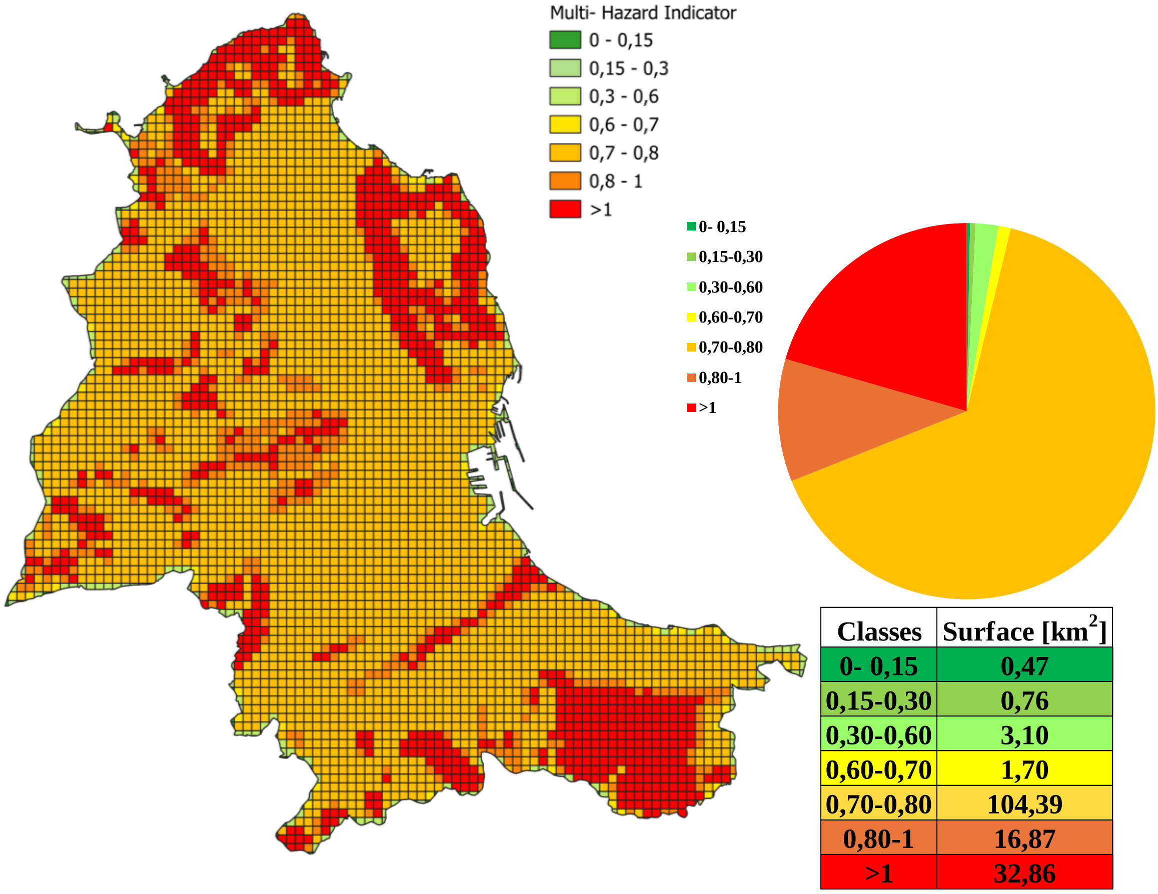
$A_{tot}$ represents the total area of the single cell (40000 m²).

A multi-hazard index (MHI) was calculated for each cell as the sum of the individual indicators of each hazard (*HI*j) by assuming an equal weight for each of them. It is a simplified calculation that should be viewed as part of an approach that will be further extended. Finally, the multi-hazard index was mapped at the municipal level.

$$MHI = HI_s + HI_g + HI_h + HI_c \tag{3}$$

## RESULTS

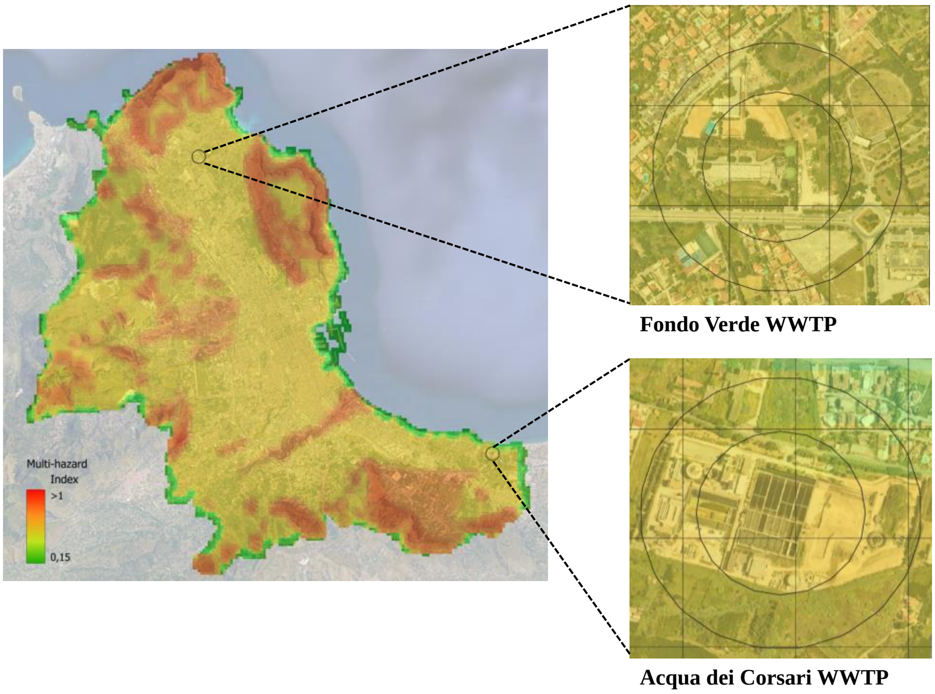
Based on the above, the multi-hazard index was calculated for each cell and subsequently mapped, distinguishing it into seven classes. Figure 3 shows that most of the territory falls in an area where the multi-hazard index takes values between 0.70-0.80, i.e., medium-high values, considering that the maximum value assumed by the index is 2.74.



| Classes | Surface [km$^2$] |
|---|---|
| 0- 0,15 | 0,47 |
| 0,15-0,30 | 0,76 |
| 0,30-0,60 | 3,10 |
| 0,60-0,70 | 1,70 |
| 0,70-0,80 | 104,39 |
| 0,80-1 | 16,87 |
| >1 | 32,86 |

Figure 3. Multi-hazard index mapping municipality of Palermo.

In addition, mapping was also carried out at the raster level to give a clearer idea of the variation of the index across the territory itself. Focusing on the two WWTPs that are present in the study area (see Figure 4), it can be observed that both fall into cells where the multi-hazard index takes a value between 0.70-0.80. It can also be seen from the table in Figure 4 that both plants have seismic events as the predominant hazard, which in this case coincides with the value of the index itself.



|  | Fondo Verde WWTP | Acqua dei Corsari WWTP |
|---|---|---|
| **$HI_s$** | 0.7502 | 0.7502 |
| **$HI_g$** | 0 | 0 |
| **$HI_h$** | 0 | 0 |
| **$Hi_c$** | 0 | 0 |
| **MHI** | 0.7502 | 0.7502 |

Figure 4. Multi-hazard index mapping of the municipality of Palermo with a focus on the two WWTPs.

## DISCUSSION

The developed multi-hazard approach significantly impacts the assessment and management of hazards for wastewater treatment plants, addressing several existing gaps in the literature. Traditionally, these plants have been evaluated for individual hazards separately, without considering the interaction between them. A challenge associated with the multi-hazard approach is that, while various assessment methods are known for the "single-hazard" approach, there are few studies on the application of the multi-hazard approach (Kappes et al., 2012). In this study, a methodology was implemented to determine a multi-hazard index for the study area, taking into account the different hazards present in the territorial context and their overlap. However, the current approach will be further improved by considering the mutual interactions of the various hazards and assigning different weights (Tilloy et al., 2019). Finally, most of the literature on the multi-hazard approach is applied in the field of territorial planning and in industrial contexts where major accidents are involved. This study aims to fill those gaps associated with the development of a multi-hazard approach related to Mayor Hazard Industries of which wastewater treatment plants are a crucial part.

## CONCLUSIONS

This tool contributes to increase awareness of territorial vulnerability based on spatial analysis. Moreover, it allows considering the combined effect of different hazards to be analysed according to a holistic approach, so as many hazards can be added. The analysis carried out in the municipality of Palermo will be extended to all municipalities in the province of Palermo and subsequently to Sicily. To conclude, the innovative aspect is that the tool is not configured as an index on a municipal basis to compare territories but ensures the visualization of variations in the index within the territory itself. The subsequent identification of possible equipment failures triggered by a natural event, and its potential consequences, can suggest to WWTP managers the correction measures to adopt in order to increase the resilience of the infrastructure.

## ACKNOWLEDGMENTS

This study was carried out within the RETURN Extended Partnership and received funding from the European Union Next-GenerationEU (National Recovery and Resilience Plan – NRRP, Mission 4, Component 2, Investment 1.3 – D.D. 1243 2/8/2022, PE0000005 - Spoke TS2).

## REFERENCES

Beltramino, S., Scalas, M., Castro Rodriguez, D. J., Brunetta, G., Pellerey, F., Demichela, M., Voghera, A., Longhi, A., Mutani, G., Caldarice, O., Miraglia, G., Lenticchia, E., & La Riccia, L. (2022). Assessing territorial vulnerability. Testing a multidisciplinary tool in Moncalieri, Italy. TEMA - Journal of Land Use, Mobility and Environment. 15(3), 355-375. https://doi.org/10.6093/1970-9870/9069

Casson Moreno, V., Reniers, G., Salzano, E., & Cozzani, V. (2018). Analysis of physical and cyber security-related events in the chemical and process industry. Process Safety and Environmental Protection, 116, 621–631. https://doi.org/10.1016/j.psep.2018.03.026

Castro Rodriguez, D. J., Beltramino, S., Scalas, M., Pilone, E., & Demichela, M. (2023). Territorial representation of a vulnerability associated with the Seveso installations in a Nord Italian case study. Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022). Research Publishing, Singapore, pp. 1463–1470. https://doi.org/10.3850/978-981-18-5183-4_r25-02-574-cd

Kappes, M. S., Keiler, M., von Elverfeldt, K., & Glade, T. (2012). Challenges of analyzing multi-hazard risk: A review. Natural Hazards, 64(2), 1925–1958. https://doi.org/10.1007/s11069-012-0294-2

Krausmann, E., Cruz, A., & Salzano, E. (2017). *Natech risk assessment and management-Reducing the risk of natural-hazard impact on hazardous installations*. Elsevier, 254 pp. https://www.sciencedirect.com/book/9780128038079/natech-risk-assessment-and-management

Labonté-Raymond, P. L., Pabst, T., Bussière, B., & Bresson, É. (2020). Impact of climate change on extreme rainfall events and surface water management at mine waste storage facilities. Journal of Hydrology, 590, 125383. https://doi.org/10.1016/j.jhydrol.2020.125383

Langsdorf, S., Löschke, S., Möller, V., Okem, A., Officer, S., Rama, B., Belling, D., Dieck, W., Götze, S., Kersher, T., Mangele, P., Maus, B., Mühle, A., Nabiyeva, K., Nicolai, M., Niebuhr, A., Petzold, J., Prentzler, E., Savolainen, J., …, & Weyer, N. (2022). IPCC, 2022: Summary for Policymakers. In Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 3–33). Cambridge University Press. www.environmentalgraphiti.org

Li, J., Li, X., Liu, H., Gao, L., Wang, W., Wang, Z., Zhou, T., & Wang, Q. (2023). Climate change impacts on wastewater infrastructure: A systematic review and typological adaptation strategy. Water Research, 242, 120282. https://doi.org/10.1016/j.watres.2023.120282

Masud, S., & Khan, A. (2024). Policy implementation barriers in climate change adaptation: The case of Pakistan. Environmental Policy and Governance, 34(1), 42–52. https://doi.org/10.1002/eet.2054

Mladineo, N., Mladineo, M., Benvenuti, E., Kekez, T., & Nikolić, Ž. (2022). Methodology for the assessment of multi-hazard risk in urban homogenous zones. Applied Sciences (Switzerland), 12(24), 12843. https://doi.org/10.3390/app122412843

Pang, T., Wang, X., Nawaz, R. A., Keefe, G., & Adekanmbi, T. (2023). Coastal erosion and climate change: A review on coastal-change process and modeling. AMBIO A Journal of the Human Environment, 52(12), 2034–2052. https://doi.org/10.1007/s13280-023-01901-9

Pilone, E., Casson Moreno, V., Cozzani, V., & Demichela, M. (2021). Climate change and NaTech events: A step towards local-scale awareness and preparedness. Safety Science, 139. https://doi.org/10.1016/j.ssci.2021.105264

Shakou, L. M., Wybo, J. L., Reniers, G., & Boustras, G. (2019). Developing an innovative framework for enhancing the resilience of critical infrastructure to climate change. Safety Science, 118, 364–378. https://doi.org/10.1016/j.ssci.2019.05.019

Tilloy, A., Malamud, B. D., Winter, H., & Joly-Laugel, A. (2019). A review of quantification methodologies for multi-hazard interrelationships. Earth-Science Reviews, 196, 102881. https://doi.org/10.1016/j.earscirev.2019.102881

UNDRR. (2020). Hazard definition classification and review. International Science Council.